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# Effects of Watershed Use on Water Quality and Fisheries in an Arizona Mountain Lake

Carla J. Fisher and Charles D. Ziebell



#### ABSTRACT

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Historical information and analyses of lake bottom sediment suggest watershed use prior to impoundment had a greater influence on water quality in Cooley Lake, Arizona, than does present land use activity.

During the summer, dense algal blooms occurred, the lake stratified, and anoxic conditions developed beneath the thermocline. A combination of water temperatures above 20° C, pH values over 10.0, and un-ionized ammonia concentrations from 0.109 to 0.225 mg/l in the epilimnion was most likely responsible for rainbow trout (*Salmo gairdneri* Richardson) mortalities in live box tests. Water quality in the lake is too poor between mid-July and September to support a rainbow trout fishery.

Keywords: Water quality, trout, fish habitat

Effects of Watershed Use on Water Quality  
and Fisheries in an Arizona Mountain Lake

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## Management Implications

Trout reared in hatchery water (pH 7.2-7.5) and stocked in Cooley Lake or other White Mountain lakes (pH 9.5-10.2) are likely to suffer pH shock. Trout surviving the pH shock may not survive the toxicity of un-ionized ammonia present from mid-July to September, the peak fishing season.

Stocking trout under these circumstances is not advisable; therefore, adjustments should be made in current management practices, along with monitoring water quality during the critical summer period, to provide data for evaluating lake conditions.

## Introduction

Most man-made lakes on the Fort Apache Indian Reservation in the White Mountains of Arizona are eutrophic, exhibiting heavy algal blooms and extensive growths of rooted aquatic plants during the summer. These conditions developed within 5 or 6 years after the impoundments were constructed, an indication of premature eutrophication.

Man-made lakes have two initial sources of nutrients which support their enrichment: (1) organic matter present in the basins before impoundment, and (2) nutrients from the watershed produced by cultural and natural processes. Nutrients present in the lake basins before impoundment may provide a large enough reserve of nitrogen and phosphorus to initiate eutrophication and support this eutrophic state when they are recirculated within the lake. Subsequent enrichment from natural sources, campground activities, and cattle defecating in intermittent inflow streambed near the lake can maintain or enlarge the nutrient pool. Lakes with these nutrient sources are inclined to remain eutrophic.

However, the algal blooms in eutrophic lakes are associated with dynamic biological and chemical interactions that frequently degrade the water quality to the point where it is unsuitable

for a variety of aquatic organisms, including fish. In lakes in which recreational fishing is the primary use, degradation of water quality is a serious problem. Consequently, this study was developed with a dual purpose: (1) to investigate watershed uses and attempt to determine the sources of nutrients, and (2) to define the extent of eutrophication and its subsequent effects on the trout fishery.

## Description of Study Area

Cooley Lake is located near McNary, on the Fort Apache Indian Reservation in the White Mountains of Arizona (fig. 1). The elevation is 2100 m, and the area of the watershed is approximately 1600 ha. Typical watershed vegetation is Gambel oak (*Quercus gambelii* Nutt.), juniper (*Juniperus* spp.), ponderosa pine (*Pinus ponderosa* Laws.) and open grassland meadows.

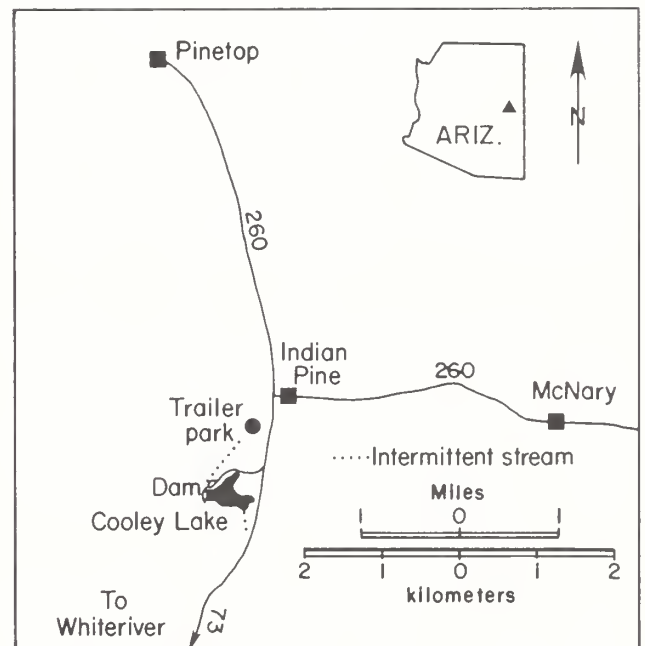


Figure 1. Location of Cooley Lake on the Fort Apache Indian Reservation near McNary, Ariz.

Annual rainfall in the area is approximately 50 cm. Winter snowfall is usually heavy, and the lake surface freezes. Summers are mild with heavy rainstorms in July and August.

An earthen dam was constructed and the impoundment filled in 1963. Full-pool surface area is 4.4 ha, maximum depth is 9.0 m, and mean depth is 7.3 m. The dominant rooted aquatic plant is *Myriophyllum* spp. The lake inflow is intermittent, depending on the amount of rainfall or snowmelt.

A stock tank in the basin received heavy cattle use for approximately 50 years before impoundment. The shoreline is now primarily used for fishing and camping, with some cattle grazing and holding in adjacent areas of the watershed. Other potential sources of nutrients in the watershed include the resort town of Indian Pine and a nearby trailer park. Sewage from the trailer park is discharged into a small oxidation pond approximately 50 m from the main inflow stream to Cooley Lake. During periods of heavy rainfall, this pond overflows and discharges into the inflow stream to the lake.

## Methods

Sampling began March 17, 1976, and terminated October 9, 1976.

### Water Quality

Dissolved oxygen (D.O.), temperature, and hydrogen-ion concentrations (pH) were measured with portable instruments in the field. A YSI<sup>1</sup> model 54 was used for D.O. and temperature, and an Analytical Measurements Model 707-B meter was used for pH.

All colorimetric analyses were made using a G. K. Turner Model 330 spectrophotometer. Hach Chemical Company tests were used and standard solutions prepared according to Standard Methods for Examination of Water and Wastewater (American Public Health Association 1971).

Ammonia-nitrogen (NH<sub>3</sub>-N) was determined by the Nesslerization method. Samples were analyzed with the spectrophotometer at a wave length of 420 nm. Nitrate was determined using the cadmium-reduction method and analyzed at a wave length of 560 nm. The ascorbic acid method was used for ortho-phosphate analyses. Spectrophotometer wavelength was 700 nm. Alkalinity was measured by potentiometric titrations with

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<sup>1</sup> The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

0.02 N H<sub>2</sub>SO<sub>4</sub> and methylene blue-bromocresol green indicator.

### Lake Sediment Analysis

Core samples were collected in the deepest areas with a Phleger Corer, Model 840-A. Cores ranged from 10 to 20 cm deep, depending on the type of substrate. Samples were placed in jars, put on ice, and transported to the fishing unit laboratory where 4 cm from the upper and lower portions of the core were prepared for analysis of total nitrogen, total phosphorus, and percent organic matter. Analysis was conducted by the University of Arizona Soils, Water, and Engineering Lab.

### Algae and Light Penetration

Samples for the examination of algae were taken concurrently with those for water quality analysis. They were preserved with Lugols solution and later identified and counted in the laboratory. A phase contrast microscope was used to identify and count algae. A random line scan was done until at least 100 of the dominant species and at least 500 total organisms had been counted. Light penetration was measured with a standard 20-cm diameter Secchi disc. Readings were recorded to the nearest 0.1 m.

### Live Box Bio-assays

Live box studies were conducted in Cooley Lake when water quality deteriorated to a point which might be harmful to trout. Cube-shaped boxes (65 cm per side) were covered with netting (12-mm mesh) and suspended in the water 0.6 m below the surface. Rainbow trout (*Salmo gairdneri* Richardson), reared at the Alchesay National Fish Hatchery, were obtained from a hatchery truck making routine stocking trips. Usually 10 fish were placed in the live boxes after they had been gradually acclimated to lake water temperatures for approximately 45 minutes. Mortalities were recorded at various intervals for a 24-hour period.

## Results

### Water Quality

Cooley Lake began to thermally stratify in April and remained stratified into early October when the study was terminated. The most pronounced stratification was from mid-July to mid-August when water temperatures in the epilimnion ranged from 18.5° to 23° C. During this period, D.O. concentrations above 5.0 mg/l were found only down to a depth of 1.5 m (fig. 2), and at 2 m and below, D.O. was 2.8 mg/l or less. By September 1, D.O. increased to 4.4 mg/l at 2 m.

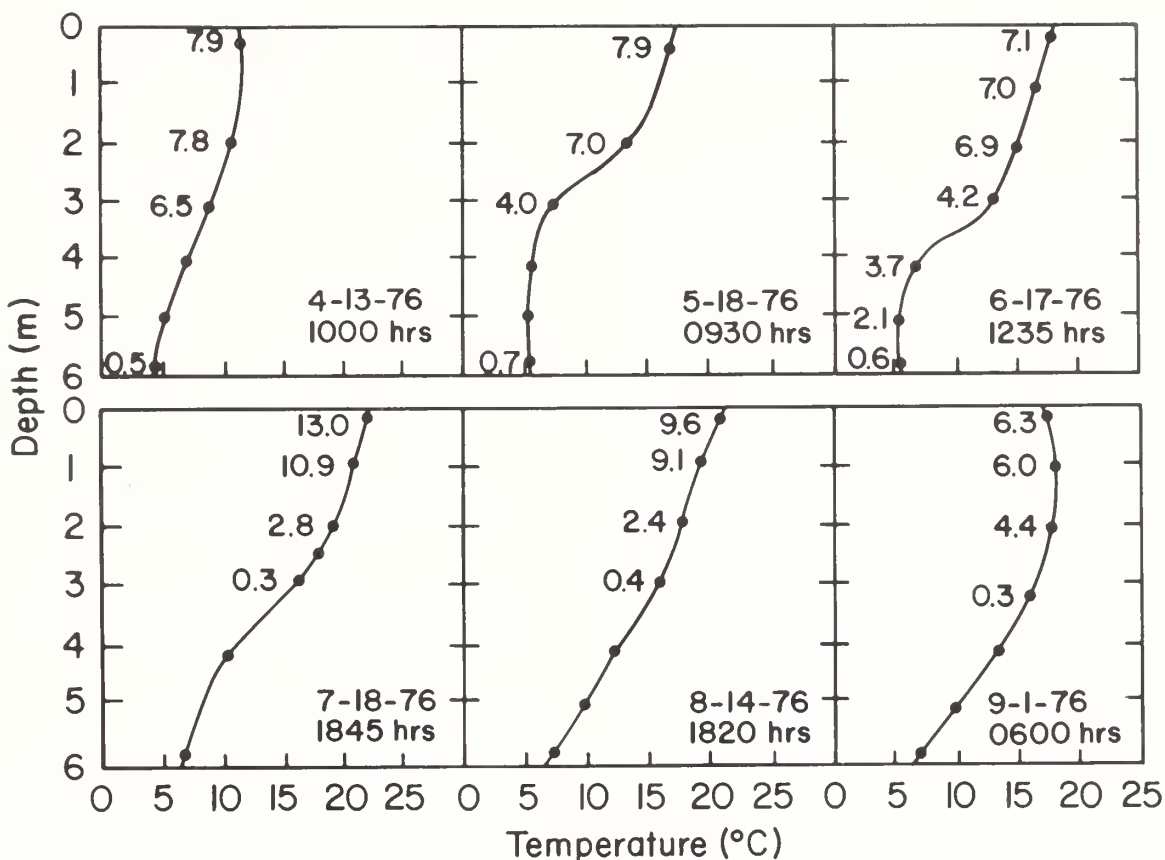


Figure 2. Selected typical temperature and dissolved oxygen relationships of Cooley Lake. Oxygen values (mg/l) are indicated at various depths on temperature curves.

Alkalinity ranged from 55 to 77 mg/l in the epilimnion between June and September. Concurrently, pH values ranged from 9.22 to 10.20 (table 1) in waters with more than 5 mg of oxygen per liter. Diel changes in pH values never exceeded 0.3 from sunset to sunrise.

Seasonal ortho-phosphate fluctuations in Cooley Lake near the surface and at 3 m are given in figure 3. Concentrations generally ranged from 0.0 to 0.10 mg/l except in mid-August at 3 m when 0.28 mg/l was recorded. Water at this depth was anoxic at that time.

Table 1.--Seasonal changes of pH in the epilimnion of Cooley Lake during June, July, and August

Depth (m)	Date													
	6/11	6/15	6/25	7/2	7/12	7/18	7/19	7/24	7/30	8/3	8/8	8/14	8/24	8/31
Surface	9.08	9.02	8.70	9.32	9.35	10.20	9.97	9.97	9.63	9.80	9.65	9.65	9.52	9.35
1	-	-	9.0	-	9.45	9.85	9.85	10.02	9.56	9.68	9.52	9.68	9.48	9.28
2	-	-	-	9.22	9.25	9.50	9.55	9.43	9.35	8.28	9.25	9.20	9.28	9.25
3	7.58	8.90	9.0	8.12	7.90	7.90	8.80	-	-	-	-	-	-	-

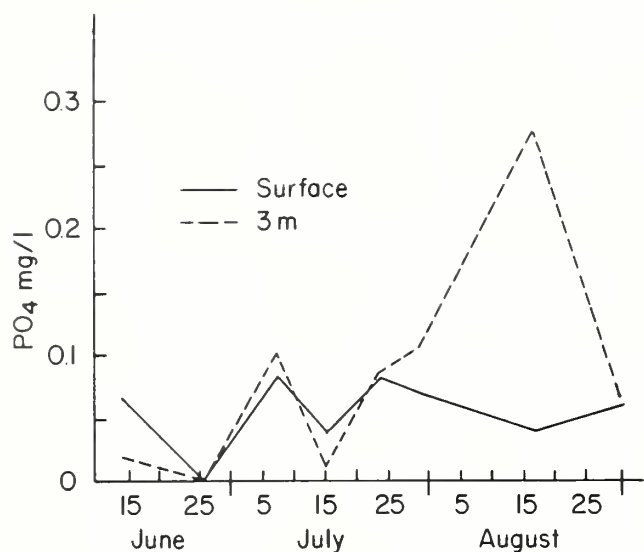


Figure 3. Seasonal ortho-phosphate fluctuations in Cooley Lake near surface and at 3 m.

Ammonia-nitrogen concentrations in the upper water of Cooley Lake during the summer ranged from 140 to 425  $\mu\text{g/l}$  (fig. 4) with one exception. A sample at 3 m on July 24 contained 780  $\mu\text{g/l}$ . This occurred during a period of heavy rainfall and was reflected by  $\text{NH}_3\text{-N}$  contributions from the inflow stream (table 2). Ammonia-nitrogen concentrations in the hypolimnion at 9 m ranged from 1000 to 1450  $\mu\text{g/l}$  between June and September.

Additional chemical contributions from the tributary to Cooley Lake are given in table 2.

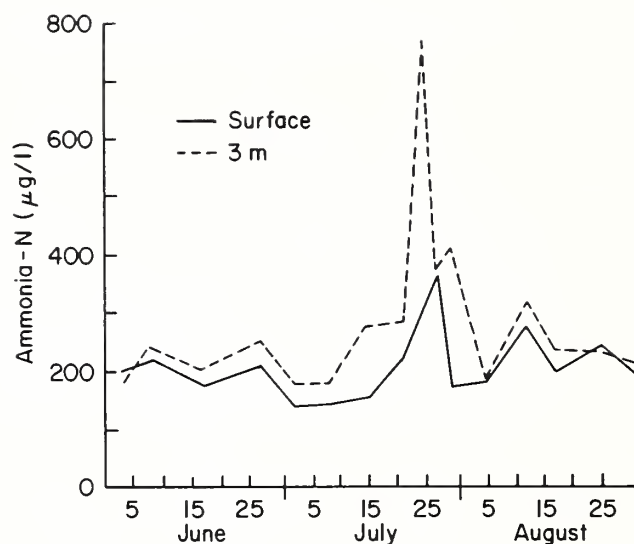


Figure 4. Seasonal ammonia-nitrogen concentrations in the upper 3 m in Cooley Lake.

#### Algae Blooms and Light Penetration

Algal density fluctuated during the summer. General increases occurred from the end of June to the latter part of July (highest peak of the season), and then decreased in August and September (fig. 5). The dominant species was *Anabaena spiroides*, a blue-green algae, which frequently made up over 90% of the algae present. Secchi disc readings reflected algal densities. When bloom density was at its peak, in the latter part of July, Secchi disc depth was 0.7 m, and

Table 2.--Chemical analyses of tributary (in mg/l) immediately before entrance into Cooley Lake

Date	Total alkalinity	$\text{NH}_3\text{-N}$	$\text{NO}_3$	$\text{PO}_4$
4/27	57	0.33	0	0.105
5/09	81	0.08	0	0.100
5/18	78	0.60	0.027	0.265
7/21	43	0.48	0	0.325
7/30	43	0.56	0	0.085
8/05	92	0.37	0	0.135

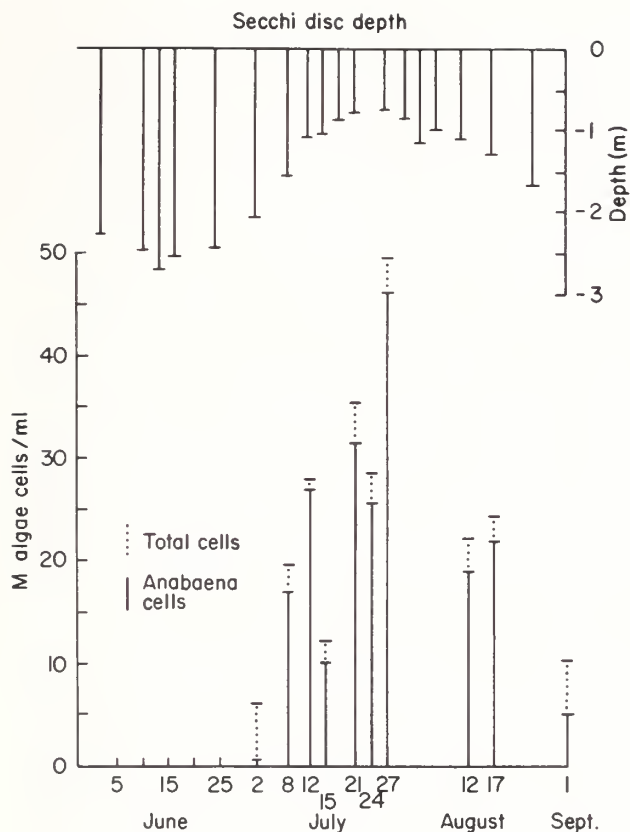


Figure 5. Algal bloom density and Secchi disc readings for Cooley Lake.

when algal densities were low (July 2), the Secchi disc depth was 2.2 m.

#### Bottom Sediments

Total nitrogen concentrations in bottom sediments at both ends of the lake were quite similar. This was also the case with total phosphorus concentrations. Total nitrogen ranged from 1777 to 2619 p/m in the upper 4 cm of the core sediments and from 1423 to 1966 p/m in the lower 4 cm.

Total phosphorus ranged from 1223 to 1272 p/m in the upper portion of the cores and from 842 to 1096 p/m in the lower portion. Organic material ranged from 14% to 16%.

#### Live Box Bio-assays

Most rainbow trout in Cooley Lake were killed between July 21 and 28 (table 3). On July 21, after 8 hours of exposure, 90% of the fish died; 100% died in 24 hours. In the second bioassay, 75% died, and in the third, 20% of the fish died. Un-ionized ammonia concentration during the bioassay ranged from 0.109 to 0.225 mg/l.

#### Discussion

Multiple interacting factors must be considered to define the problems associated with eutrophication in Cooley Lake. During the study, summer algal blooms occurred, the water

Table 3.--Rainbow trout mortalities in live boxes and associated un-ionized ammonia (NH<sub>3</sub>) concentrations in Cooley Lake at 0.5

Date and time	Un-ionized ammonia (mg/l)	Percent mortality
7/21 1000 hr	0.158	Test fish placed in live box
7/21 1800 hr		90
7/22 1000 hr	0.172	100
7/27 1000 hr	0.225	Test fish placed in live box
7/28 1000 hr	0.171	75
8/04 1000 hr	0.109	Test fish placed in live box
8/05 1000 hr	0.112	20



stratified, and anoxic conditions developed beneath the thermocline. Within these problem areas, several chemical and biological interrelationships adversely affected rainbow trout.

#### Algal Bloom and Hydrogen-ion Concentrations (pH)

Algal bloom density continuously increased from spring through early summer and then peaked near the end of July (fig. 5). The prediction of such peaks and their significance to the fishery are pertinent to management practices. A system was used to predict "summer fish kill risk" (Barica 1975) which was related to algal bloom density. The system was based on parameters such as  $\text{NH}_3\text{-N}$ , Secchi disc transparency and D.O. According to Barica (1975), if  $\text{NH}_3\text{-N}$  concentrations ranged from 600 to 800  $\mu\text{g/l}$  for 3 to 10 days, with Secchi disc depths of 0.3 to 0.4 m and minimum daytime D.O.'s of 4.0  $\text{mg/l}$  occurring from 1 to 6 days, then a bloom collapse and oxygen depletion would be expected. In the epilimnion of Cooley Lake ammonia-nitrogen did not reach the levels of Barica's index. Also minimum D.O.'s were higher and Secchi disc transparency was deeper than Barica indicated was necessary to predict "summer kill." Our analyses showed ammonia-nitrogen concentrations were 300 to 400  $\mu\text{g/l}$ . D.O. was above 6.0  $\text{mg/l}$ , and Secchi disc readings were 0.7 to 0.8 m. A heavy bloom of *Anabaena spiroides* did occur, but no bloom collapse or marked oxygen depletion took place.

Although conditions in Cooley Lake were not as severe as Barica found in the Canadian prairie lakes, it appears that the predictive system has merit and may be applicable for management use in other White Mountain lakes.

In conjunction with the algae blooms, an aberrant diel pH fluctuation developed in Cooley Lake. Normally, pH peaks in the late afternoon when algae are using  $\text{CO}_2$  and producing oxygen by photosynthesis. Then during the dark period, when  $\text{CO}_2$  is respired, the reverse is expected, which would cause a lowering of pH values by possibly 1.5 to 2.0 units. This did not occur in Cooley Lake.

In mid-June, the lake was stratified at 3 m, and the pH had increased to about 9.0 in the epilimnion (table 1). As the summer progressed, a slow rising trend continued. On July 18, the late afternoon pH was 10.2 near the surface. At 5:30 a.m. the next day, the near surface pH was 9.9, only 0.3 less than the previous afternoon. Concurrently, D.O. was reduced only from 13.8 to 11.1  $\text{mg/l}$ . These sustained high pH values were contrary to what was expected during periods of heavy algae blooms. The reason for this phenomenon was unclear, but it is suspected that a relationship existed between some unmeasured biological activity and low dissolved oxygen loss during the night.

#### Lake Stratification and its Related Effects

The marked thermal and D.O. stratification had a substantial influence on the fishery of Cooley Lake. The lake was stratified at different depths from April through September (fig. 2), but the most pronounced effects were observed between July 13 and September 1, 1976. During this period, only the upper 1.5 to 2.0 m of water maintained D.O. concentrations capable of supporting fish. This condition forced the trout to remain in the upper water strata where temperatures were never lower than 18° C and were usually between 20° and 25° C. This is above the optimum temperature range of 15° to 19° C for rainbow trout (McAfee 1966). Although D.O. was acceptable, the high temperatures could cause additional stress to the fish concurrently subjected to pH values of 9.5 and above. These interrelationships between high temperature and pH produced undesirable water quality conditions for trout and were further complicated by the presence of ammonia-nitrogen.

Ammonia is produced by heterotrophic bacteria when appreciable amounts of organic material are present in the hypolimnion and in bottom sediments of stratified lakes. The accumulation of  $\text{NH}_3\text{-N}$  markedly increased when the hypolimnion becomes anoxic (Wetzel 1975), and concentrations then increase above the thermocline. The specific origin of  $\text{NH}_3\text{-N}$  in the epilimnion has not been identified by Hutchinson (1957), Wetzel (1975), or Cole (1975), although some examples of the occurrence have been presented. One possibility would be the slow molecular diffusion from the anoxic waters of the hypolimnion aided by wind-induced water circulation at the anoxic-oxic water interface.

Many investigators (Burrows 1964, Trussell 1972, Rice and Stokes 1975) have pointed out that ammonia in the un-ionized form ( $\text{NH}_3$ ) is highly toxic to many organisms, especially fish. Un-ionized ammonia is calculated from  $\text{NH}_3\text{-N}$  values (Trussell 1972) as a dissociation function of pH and temperature (i.e., as pH and temperature increase, un-ionized ammonia increases).

In Cooley Lake, during the critical summer period,  $\text{NH}_3\text{-N}$  in the epilimnion (fig. 4) generally increased to levels where un-ionized ammonia concentrations could be toxic to fish. In addition, an unusually high concentration (750  $\mu\text{g/l}$ ) was recorded on July 24 at 3 m (fig. 4). The  $\text{NH}_3\text{-N}$  most likely originated at the overflow from the oxidation ponds below the trailer park which subsequently entered the lake via the intermittent stream (table 2). Since inflow stream waters were cooler (18° C) than upper lake waters (22° C) but were warmer than the water at 3 m (16.2° C), the main flow pattern remained above the thermocline and anoxic stratum. The inflow  $\text{NH}_3\text{-N}$  would then accumulate in the lake because of the thermal stratification, thus accounting for the temporary marked increase shown in figure 4.

Rice and Stokes (1975) showed that the 24-hour TL<sub>50</sub> for rainbow trout was 0.097 mg/l NH<sub>3</sub>, and Westers and Pratt (1977) suggested that un-ionized ammonia concentrations not be allowed to exceed 0.0125 mg/l for salmonid hatcheries. A comparison of these toxicity levels with the data from Cooley Lake, NH<sub>3</sub> range 0.109 to 0.225 mg/l (table 3), indicates that un-ionized ammonia existed at near lethal or lethal levels for rainbow trout.

#### Overall Effects on Rainbow Trout

The marked stratification during the summer forced the fish to inhabit only the upper 1.5 to 2.0 m of water, where sufficient dissolved oxygen was available. Within this zone, the combination of elevated pH values, high water temperatures, and un-ionized ammonia produced conditions that were harmful to trout. Data from in situ live box tests during this critical period showed mortalities from 20% to 100% in three series of 24-hour exposures (table 3). When the most trout died, the pH was 9.6 to 9.8, D.O. 8.2 to 11.0, temperature 20° to 21° C, and un-ionized ammonia concentrations ranged from 0.109 to 0.225 mg/l. These data suggest that the combination of high pH and un-ionized ammonia was most likely responsible for the mortalities.

The fishery implications are twofold. First, the trout stocked in Cooley and other White Mountain lakes are reared in hatchery water with a pH range of 7.2 to 7.5. When they are transferred to the lakes where pH ranges from 9.5 to 10.2, there is a strong potential for pH shock. Second, even if the trout survive the pH shock, chances for survival are reduced because of the toxicity of the un-ionized ammonia. The live box tests support this conclusion. The management problems associated with these conditions are serious, because mid-July to September is the peak of the fishing season, and then the water quality is too poor to support a rainbow trout fishery.

#### Lake Eutrophication and Watershed Influences

The degree of eutrophication of Cooley Lake was well defined, and past nutrient contributions most likely responsible. Cattle manure in the close proximity of the tank provided nutrients to sediments that are now at the lake bottom. Nutrients move from bottom muds to the water above (Hynes and Greib 1970, Keeney 1972). Lake sediments typically have 50 to 200 kg/ha of N per 10 cm depth (Keeney 1972). Analysis of sediment samples from Cooley Lake showed that N ranged from 1298 to 2389 kg/ha per 10 cm depth, concentrations far above normal. These data suggest excess nitrogen was probably present before the lake filled. The nitrogen, usually as NH<sub>3</sub>-N, is currently being recycled (Porcella

et al. 1972, Schindler et al. 1971). Current input sources of N and P do not appear to be of that magnitude (table 2), primarily because of infrequent inflow and greater dispersion of cattle and their fecal material.

One infrequent nutrient source was the trailer court located approximately 1 km above the lake. Domestic sewage discharged from trailers into an oxidation pond occasionally overflowed during heavy rainfall and entered an intermittent tributary to the lake. The tributary flowed for approximately 10 days the latter part of July and contributed phosphate and ammonia-nitrogen from the pond. This coincided with some of the worst water quality conditions of the summer.

Some cattle still graze on the watershed, particularly at the southeast end of the lake within the main drainage area. Lack of specific information on numbers of cattle and length of grazing duration prohibited an evaluation of their effect on lake eutrophication. Additional study is needed to determine if cattle grazing influences the current water quality of the lake.

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